The International Space Station as a Long-duration Space Exploration Test bed

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ISS As an Operations and Technology Validation Test bed

- **ISS serves as a platform for complex Engineering Integration as well as scientific research**

- **Serves as a facility to gain operational experience and technological validation in:**
  - Crew Operations
  - Spacecraft Systems Operations, and
  - Crew-System Interface Operations

ISS as an enabler to Exploration: Research enabled by ISS

Research in life and physical sciences will enable exploration.

Research enabled by ISS

Life Sciences

- Behavioral health
- Human factors
- Cardiovascular function
- Musculoskeletal fitness
- Immune function
- Pharmacology
- Radiation protection
- Toxicity of atmospheric contaminants & dust
- Biological life support systems

Physical Sciences

- Partial gravity effects
- Mixing of cryogenic fluids
- Multiphase flow
- Heat transfer
- Materials processing & recycling

Key Capabilities for Exploration

- Maintaining human health & performance on long-duration missions
- Technology demonstration testbed (e.g., cryogenic fluid management, energy storage)
- Closed-loop life support to minimize consumables on long-duration missions
- Autonomous crew operations far from Earth

Current ISS Utilization to 2016: Human Research, Microgravity Sciences, Technology Development

- **ISS Focus for NASA**
  - Astronaut health and countermeasure development
  - Research and technology developments
  - Life and Physical Sciences in Microgravity
  - Developing and validating operational procedures
- **Content**
  - Astronaut health and countermeasure development
    - Muscle and Bone Loss, Cardiovascular Changes, Neurovestibular Changes, Behavioral Health and Performance, Pharmacology, Nutrition
    - Involves significant research collaborations with International Partners
  - Research and Technology
    - Environmental Monitoring and Control technologies
    - Life Support technologies
  - Life and Physical Sciences in Microgravity
    - Basic and applied research that utilizes existing flight hardware and ISS facilities in the areas of fluid physics, combustion science, materials science, and biological sciences
    - Involves significant research collaborations with International Partners
  - Operational Procedures
    - International operational coordination and integration

ISS Exploration Utilization 2016 to 2020: Astronaut health and countermeasure development

- **ISS is in the critical path for reducing human health and performance risks for exploration**
  - Allows validation of techniques and technologies needed for the moon and particularly the transit phase of a Mars mission.
- **NASA's Human Research Program identified 27 high priority human health risks that require research activities to mitigate**
  - 21 of the 27 risks require the ISS (79 studies) to gather information to understand the risk, validate countermeasures, or validate technologies required to monitor or treat the adverse outcome
  - Integrated research planning indicates:
    - By 2016, the HRP will complete most of the research needed to identify and quantify risks to human health and performance and will have begun to validate potential countermeasures for Muscle Mass, Strength and Endurance
    - Twelve of the 21 risks have investigations that extend into the 2016-2020. Two of the 12 risks are important to reduce prior to lunar outpost and three are critical to reduce prior to any Mars mission.
- **Clear need for the ISS beyond 2016 and through at least 2020 to complete the studies necessary to quantify and understand the severity of certain risks, and to complete the development of key countermeasures**
  - For Mars missions, the ISS is the only platform that provides the microgravity environment of a Mars transit and there will be no new opportunities.

Crew Health and Safety Risks

Blue – ISS investigations required
Red – Critical to reduce before ISS retirement

Space Human Factors & Habitability Risks

- Risk of Error Due to Inadequate Information
- Risk Associated with Poor Task Design
- Risk of Reduced Safety and Efficiency Due to An Inadequately Designed Vehicle, Environment, Tools, or Equipment
- Risk of Adverse Health Affects from Lunar Dust Exposure
- Risk of Inadequate Food System

Behavioral Health & Performance Risks

- Risk of Behavioral and Psychiatric Conditions
- Risk of Performance Errors Due to Sleep Loss, Circadian Desynchronization, Fatigue and Work Overload
- Risk of Performance Errors Due to Poor Team Cohesion and Performance, Inadequate Selection/Team Composition, Inadequate Training, and Poor Psychosocial Adaptation

Space Radiation Risks

- Risk of Radiation Carcinogenesis
- Risk of Acute Radiation Syndromes Due to Solar Particle Events
- Risk of Acute or Late Central Nervous System Effects from Radiation Exposure
- Risk of Degenerative Tissue or other Health Effects from Radiation Exposure

Exploration Medical Capability Risks

- Risk of Inability to Adequately Treat an Ill or Injured Crew Member

Human Health Countermeasures Risks

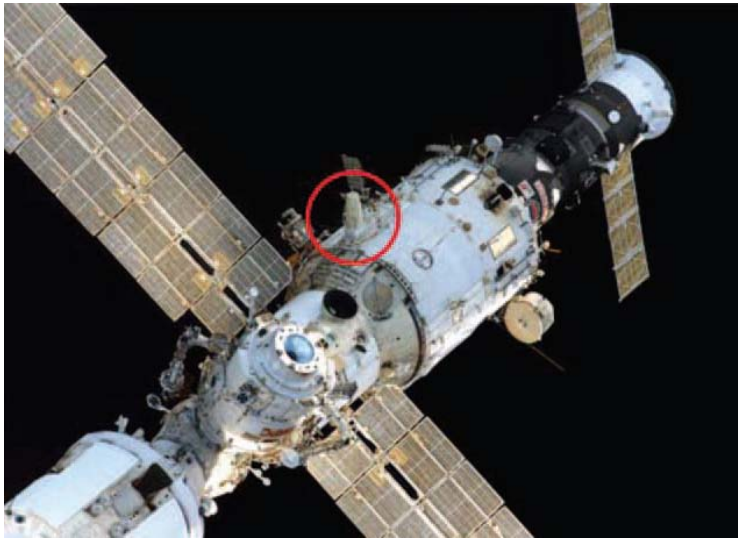
- Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems
- Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance
- Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity
- Risk of Accelerated Osteoporosis
- Risk of Orthostatic Intolerance During Re-Exposure to Gravity
- Risk Factor of Inadequate Nutrition
- Risk of Bone Fracture
- Risk of Invertebral Disc Damage
- Risk of Renal Stone Formation
- Risk of Cardiac Rhythm Problems
- Risk of Crew Adverse Health Event Due to Altered Immune Response
- Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions
- Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems
- Risk of Therapeutic Failure Due to Ineffectiveness of Medicine

ISS as a Technology Testbed (2016 to 2020): Astronaut Health

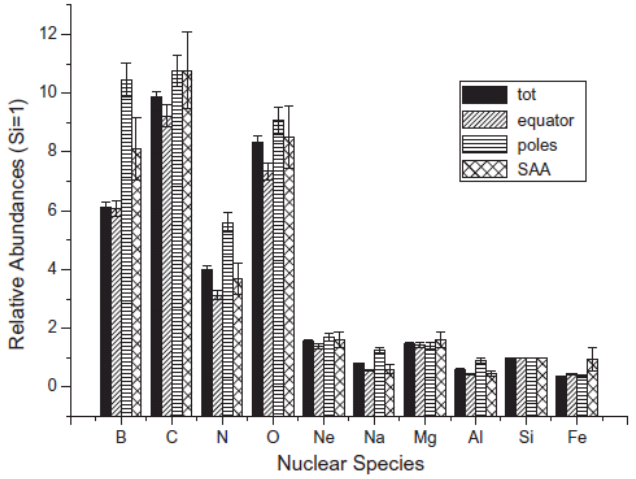
- **Developing the technologies and gaining operational experience to meet the level of medical care standards for space exploration missions, is critical to developing a robust exploration program.**
- **Future ISS utilization for Astronaut health would include:**
  - Diagnosis and Treatment Hardware Evaluations
    - In-situ IV water production
    - Validate ultrasound technology as prime imaging capability
    - Test advanced trauma care equipment
    - Evaluate in-flight laboratory analysis devices while having the opportunity to return samples to Earth for validation of measurements
    - Advanced spaceflight dentistry hardware and techniques
    - Kidney stone ablation hardware
    - Biomedical sensors for routine and contingency health care scenarios
  - Telemedicine
    - Refine medical operation concepts with variable delays in communication with ground flight surgeons and controllers.
  - Medical Informatics
    - Validation of models that forecast injury and illness incidence rates
    - Test medical procedure viewing systems that guide crew without assistance from ground

ISS Contributions to Space Radiation Protection

- The ISS is shielded from low to medium energy galactic cosmic rays (GCR) and solar particles; however is providing new insights and methodology improvements relevant for exploration space radiation concerns
  - Important findings in space environments, transport code validation and health risks have been achieved
- Space Environments
  - Collection of more than one solar cycle of data on GCR and trapped radiation
  - NASA, ESA, JAXA and RSA measurements of GCR and trapped protons with proportional counters and charged particle telescopes
  - Neutron spectroscopy by JAXA Bonner ball experiments provided detailed geographic and neutron energy data sets
  - New models of ISS trapped environment and GCR solar modulation were developed



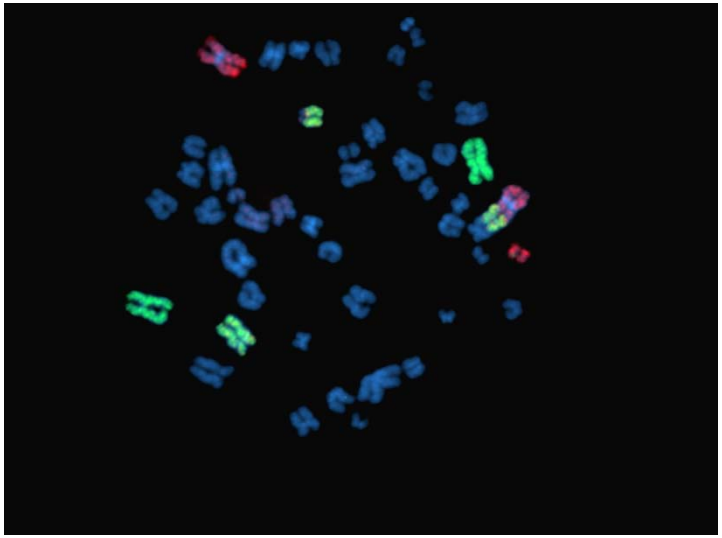
Matroshka Phantom outside Zvesda module



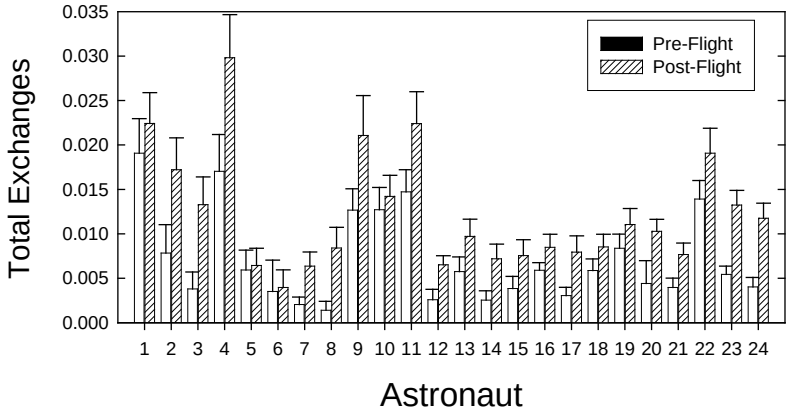
ASI GCR telescope data from ISS

ISS Contributions to Space Radiation Protection- continued

- Organ Exposure Estimates
  - Phantom Torso experiments by NASA, ESA, and RSA showed excellent agreement with NASA models of radiation transport in spacecraft and human tissues
    - **Verified that >80% of ISS organ dose equivalents is from GCR**
  - Phantom and other environmental measurements used to verify accuracy of NASA HZETRN computer code of radiation transport and shielding evaluation methods
- Radiations Health Risks
  - Biodosimetry studies revealed in increase in chromosomal aberrations in all astronauts tested.
  - A good correlation of biodose estimates with equivalent dose estimates from HZETRN/QMSFRG code is observed



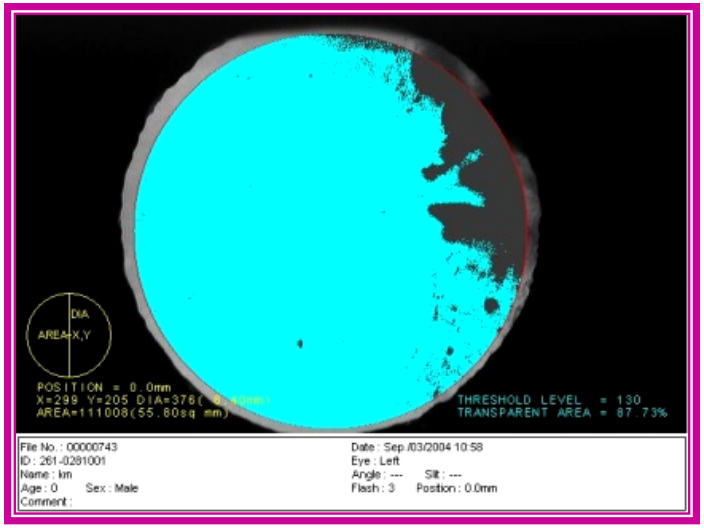
Chromosome aberrations from ISS blood cells



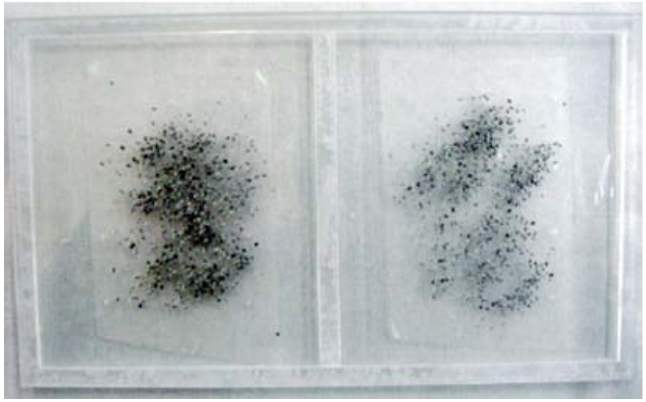
ISS crew results for increased aberrations frequency

ISS Contributions to Space Radiation Protection- continued

- NASA Study of Cataracts in Astronauts (NASCA) showed an increase occurrence of cortical and posterior subcaspular (PSC) cataracts at small lens doses in a cohort of 224 astronauts including most NASA ISS crew
  - The number of PSC centers increased by GCR
  - Progression rates for cortical cataracts found to increase with radiation exposure in less than 5 year observation period
- Space Radiobiology
  - Light Flash experiment by ASI provided new data correlating cosmic rays traversals and retinal flashes
  - Space radiobiology experiments by JAXA are studying DNA repair capacity and developmental biology after space exposures



NASCA retro-illumination image of Astronaut cataract

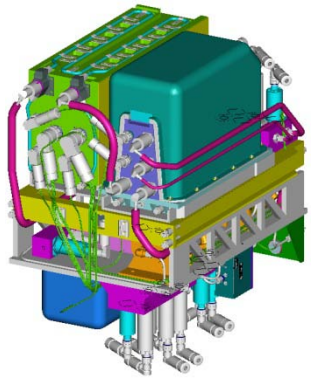


JAXA study of silkworm egg development in combined space radiation and microgravity

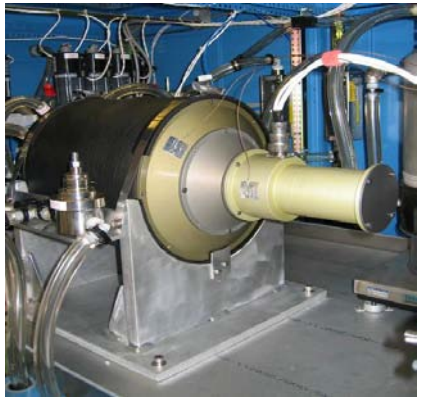
ISS –Analog to Mars Transit: Research and Technology
Test Bed for Closed Loop Life Support

- **Atmosphere Revitalization Systems (ARS)**
  - ISS ARS is currently open loop, with closure only for water vapor. R&TD Projects are actively watching a commercial activity to integrate a Sabatier on ISS
  - Improvements over Sabatier are possible to fully recover hydrogen: Bosch, Carbon Formation Reactor, etc.
  - Demonstrations of redesigned fans with improved acoustical properties
- **Regenerative Water Recovery**
  - Further close water loop by evaluating technologies to recover water from brines
  - Enhance crew hygiene by incorporating body wash, hand wash and laundry
  - Eliminate consumables by swapping multi-filtration beds with alternative technologies
- **Advanced Waste Management**
  - Decrease trash and consumable mass by reusing clothing
  - Decrease trash volume & increase stability of wastes by demonstrating compaction and waste dewatering technologies
- **Food Management Systems**
  - Evaluation of a vegetable production unit or “salad machine” to augment the stored food system with fresh crops

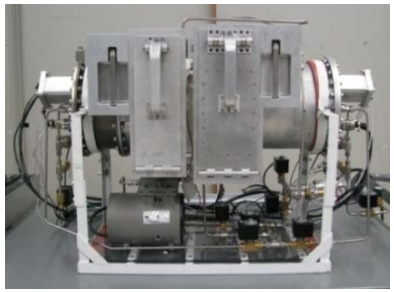

Bosch


Sabatier

Brine Water Recovery


Cascade Distillation

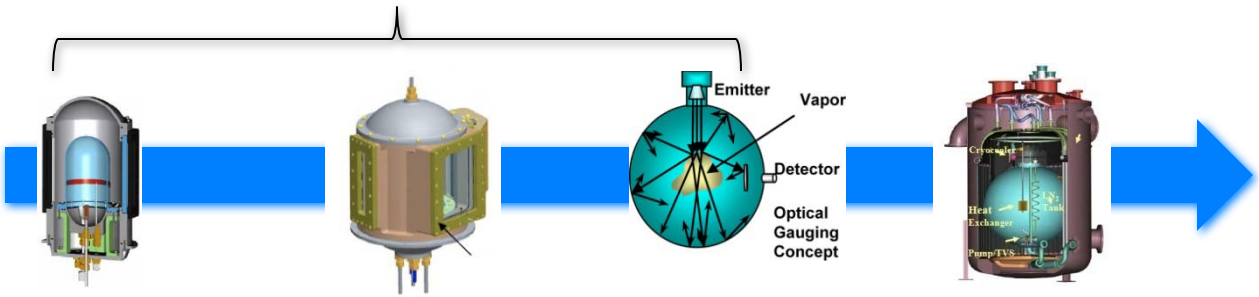

Lettuce Production Unit


Waste Compactor

Research and Technology: Cryogenic Propellant Storage & Handling

- **Fundamental microgravity research on cryogenic fluid physics could enable development of the capability to refuel exploration vehicles.**
- **Zero Boil-Off Tank (ZBOT) experiments on ISS are planned to address key technical challenges with cryogenic propellant storage and handling.**

Fundamental Research | **Technology Validation** | **Operational Capability**



ZBOT-1: Mixing & Tank Pressure Control (2011)

ZBOT-2: Active Cooling (2015)

ZBOT-3: Mass Gauging & Fluid Transfer (2018)

ISS Cryogenic Propellant Storage Demo (2020)

In-space propellant depot could enable reuse and increase delivered payload of exploration vehicles.

A Facility to Gain Operational Experience and Technological Validation

- **Irrespective of a Near Earth Object, Lunar or a Mars mission, ISS will play a crucial role for:**
  - Crew Operations
  - Spacecraft Systems Operations
  - Crew-Systems Interface Operations

- **ISS extension till 2020 would allow us to get more confidence in these functional areas**

ISS for Crew Operations

Mission Objective	Capabilities needed For Moon	Capabilities needed For Mars	ISS Role
Crew Operations and Training	Integrated International crews; Evolved operations tools and processes; Skills based IVA and EVA training; Evolved on-board training tools.	Integrated International crews; Streamlined operations tools and processes; Computer based IVA and EVA training.	Develop and demonstrate protocols and procedures with international crews; Validate hands-on space flight experience to broaden skill base for future exploration crews; Develop and demonstrate skill-based and on-board training tools, computer simulations and videos.

ISS for Spacecraft Systems Operations

Mission Objective	Capabilities needed For Moon	Capabilities needed For Mars	ISS Role
Advanced Habitation and Life Support Operations	Closed loop life support; Evolved medical care and countermeasures.	Long duration crew accommodations; Long distance crew provisioning and resupply; Advanced environmental control and life support; Long distance medical care and long duration countermeasures.	Demonstrate and evolve crew accommodations and planning systems for provisioning, food and clothing; Characterize operating conditions for next generation regenerative environmental closed loop life support; Validate advanced health care, exercise and countermeasures.

ISS for Crew-Systems Interface Operations

Mission Objective	Capabilities needed For Moon	Capabilities needed For Mars	ISS Role
Automation, Robotics and Human-Machine Interface	Combined crew and robotic operations; Robotic exploration aids and EVA support; Ground controlled robotic operations.	Autonomous crew and robotic operations with time delayed communications; Efficient crew and ground operations; Combined airlock and robotic operations.	Validate robotic designs, concepts, tools and operational scenarios for long distance assembly and maintenance tasks. Develop, test and demonstrate new procedures for in-space assembly systems;
Assembly Operations	Reliable in-space assembly operations	Autonomous in space assembly operations	Self-deploying and self-assembling systems; Inspection and control operations.

The Future of the International Space Station

- **As it nears assembly completion, the International Space Station will continue to increase its scientific productivity:**
  - Utility will depend on the COTS CRS program
  - Most scientific outfitting will be completed in the next 18 months!
  - 6 Crew members will enable additional science investigations!
  - Addition of partner laboratories will provide new opportunities for investigators
  - First flight of the ATV signals the maturation of new international partner resupply capabilities